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**SUMMARY OF RESEARCH: GRANT NsG 137-61** CR-53289

5p. 2d T in all caps: [Radiation Heat Transfer]

The research which has been performed under the subject Grant may be grouped into two broad categories: (1) studies of the heat transfer characteristics of space-vehicle radiators, (2) studies of the radiation properties of surfaces. The specific investigations which have been carried out in these problem areas will be described below. In connection with these investigations, it may be mentioned that close technical liaison was maintained at all times between Mr. S. Lieblein, technical monitor of the Grant, and E. M. Sparrow, principle investigator.

pers. auth.

UNPUBLISHED PRELIMINARY DATA

[1963] 5p refs

## Radiator Studies

At the request of Mr. Lieblein, a detailed formulation was developed for the heat transfer processes taking place in fin and tube space-vehicle radiators. This study served to unearth several specific problems which were then subjected to detailed analytical exploration. The first such detailed analysis consideredthe effect of the relative orientation of fins and tubes on the heat transfer performance (publication 1). Three potentially-interesting fin-tube arrangements were considered and definitive conclusions were arrived at regarding the relative merits of each.

The second investigation was initiated to re-examine some of the basic assumptions of space-radiator design calculations (publication 2). In particular, it is generally assumed that longitudinal heat conduction (i.e., in the direction of the tube axis) and cross radiation between nonisothermal surfaces of the radiator are negligible. The validity of these assumptions was checked by obtaining solutions which included longitudinal conduction and nonisothermal cross radiation. Once again, definitive conclusions were arrived at. In connection with the cross radiation, it was necessary to derive

12

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radiant interchange factors which were heretofore unavailable in the literature. The interchange factors were of sufficient interest in their own right so as to warrant separate presentation (publication 3).

Another assumption frequently employed in heat transfer calculations for fin-tube radiators is that adjacent tubes have the same temperature. Correspondingly, the temperature distribution in the fin joining the tubes is symmetric about a position mid-way between the tubes. In practice, such symmetry may not exist. The quantitative conditions under which asymmetries in fin temperature distribution give rise to significant effects on fin heat transfer have been determined by analysis (publication 4).

## Radiation Properties of Surfaces

The radiant emission and absorption characteristics of surfaces depends fundamentally upon intrinsic properties such as the emissivity, reflectivity, and absorptivity. However, in addition to these, the effective emitting and absorbing power of surfaces is also related to the shape of the surface. It is well known that a cavity will absorb more radiant energy than will a plane surface; correspondingly, a cavity emits more radiant energy than does a plane surface. Consequently, in the design of radiating surfaces to provide specified operating conditions (e.g., thermal-environmental control), concave surfaces provide an extra degree of freedom compared with plane surfaces in that the effective radiation properties can be altered by altering the cavity geometry. Cavity-absorption information is of direct interest in connection with such applications as solar power sources and cold walls of space-environment simulators.

In light of the foregoing, it is natural to subdivide any study of the radiation properties of surfaces into two parts: (a) cavity absorption and emission characteristics, (b) intrinsic properties.

A far-ranging analytical investigation of the absorption and emission characteristics of cavities has been performed. The various cavity configurations included in the investigation are: spherical cavity (publications 5 and 6), circular-cylindrical cavity (publication 7), v-groove cavity (publication 8), rectangular-groove cavity (publication 9), conical cavity (publication 10). In general, the results are reported in terms of an apparent emissivity and apparent absorptivity which provide a direct comparison of the emitting and absorbing power of a cavity relative to that of a plane surface.

An experimental program has been undertaken to measure the intrinsic radiation properties of surfaces. A knowledge of such properties is essential to the computation of the radiant interchange between surfaces and their surroundings. Primary consideration is being given to the measurement of the reflectivity. As a first step, an instrument was devised and constructed for measuring the total (in contrast to monochromatic) directional reflectivity of surfaces. The essential features of the instrument are as follows: A beam of black-body radiation is directed onto a test surface, the angle between the incident beam and the surface normal being adjustable. The energy reflected in some preselected direction is focused on a thermopile and recorded.

It is well-known, at least qualitatively, that surface roughness has a decisive effect on the reflectivity of a surface; however, there has been little quantitative study of the roughness effect. The instrument described in the foregoing paragraph has been emplnyed in a quantitative investigation of the effect of controlled surface roughness on the total directional reflectance of metallic surfaces (publication 11). The test surfaces were nickel rectangles whose surfaces were ground with grits of different coarseness.

The monochromatic (spectral) reflectivity is a much more fundamental quantity than the total reflectivity. This is because monochromatic information may be applied to incoming radiant beams having arbitrary wave-length distributions. However, a monochromatic measurement is much more difficult and requires more elaborate equipment than does a measurement of total radiation. The Perkin-Elmer monochrometer is an instrument capable of the desired spectral resolution. This instrument was purchased some years ago by the Mechanical Engineering Department from non-contract funds. In the immediate past,highly-precise external optics have been designed and constructed to adapt the Perkin-Elmer instrument to measurements of directional, monochromatic reflectivity. The resulting apparatus is a precision research tool capable of accommodating a broad range of surface materials.

Initial measurements of the directional reflectance of a non-metallic material, magnesium oxide, have already been carried out. These measurements were made for test samples having various degrees of surface roughness. For the aforementioned studies, the incoming beam arrived at the test surface at near-normal incidence. These experiments have revealed a rather remarkable finding,namely, that a given surface can reflect either specularly (i.e., as a mirror) or diffusely depending upon the wave length of the incident beam.

The next phase in our program is a continuation of the directional reflectivity studies on magnesium oxide, but with an incoming beam which makes a large angle of incidence with the surface normal. It is expected that the effective height of a given surface roughness would be less at larger incidence angles.

In forthcoming studies, it is planned to investigate the effect of surface roughness on the directional monochromatic reflectivity of metallic surfaces. These might include pure metals, alloys, crystals, and so forth. It is also contemplated to carry out studies of the monochromatic (spectral) emissivity of surfaces having various controlled roughnesses.

Publications Under Grant NsG 137-61


1. Heat Transfer Characteristics of Several Fin and Tube Radiators, NASA TN D-1435, November, 1962.

2. Heat Transfer from Fin-Tube Radiators, Including Longitudinal Conduction and Radiant Interchange between Longitudinally-Nonisothermal Finite Surfaces, NASA TN D-2077, December, 1963.

3. Angle Factors for Radiant Interchange Between Parallel Oriented Tubes, Trans. A.S.M.E., Series C, J. of Heat Transfer, vol. 85, November, 1963, pp. 382-384.

4. The Effect of Asymmetrical Thermal Boundary Conditions on Radiating-Fin Heat Transfer, to be published in A.S.M.E., Series C, J. of Heat Transfer.

5. Absorption and Emission Characteristics of Diffuse Spherical Enclosures, Trans. A.S.M.E., Series C, J. of Heat Transfer, vol. 84, May, 1962, pp. 188-189.

6. Absorption and Emission Characteristics of Diffuse Spherical Enclosures, NASA TN D-1289, June, 1962.

7. Efflux of Thermal Radiation from a Cylindrical Cavity Irradiated from an External Source, NASA TN D-1313, June, 1962.

8. Absorption of Thermal Radiation in V-Groove Cavities, International J. of Heat and Mass Transfer, vol. 5, November, 1962, pp. 1111-1115.

9. Thermal Radiation Absorption in Rectangular Groove Cavities, J. of Appl. Mech., vol. 30, June, 1963, pp. 237-244.

10. Radiant Emission Characteristics of Diffuse Conical Cavities, J. Optical Society of America, vol. 53, July, 1963, pp. 816-821.

11. Effect of Surface Roughness on the Total Hemispherical and Specular Reflectance of Metallic Surfaces, to be published in Trans. A.S.M.E., Series C, J. of Heat Transfer.